

# APPLICATION OF GRAVITY-GEOLOGIC METHOD OVER SOUTH CHINA SEA

Senior Thesis

Submitted in partial fulfillment of the requirements for the

Bachelor of Science Degree

At The Ohio State University

By

Stephen E. Ferreira

The Ohio State University

2017

Approved by

A handwritten signature in black ink, appearing to be 'CK Shum', written over a light grey rectangular background.

---

C. K. Shum, Advisor  
School of Earth Sciences

## TABLE OF CONTENTS

Abstract.....	ii
Acknowledgements.....	iii
List of Figures.....	iv
Introduction.....	1
Methods.....	2
Results.....	4
Discussion.....	5
Conclusions.....	8
Suggestions for Future Research.....	9
References Cited.....	10

## **ABSTRACT**

The Gravity-Geologic Method (GGM) was used to estimate a bathymetry map over an area from  $8.6^{\circ}$ ,  $110.0^{\circ}$  to  $16.9^{\circ}$ ,  $116.4^{\circ}$  (latitude and longitude) in the South China Sea. The goal of this thesis was to create a bathymetry map that more accurately estimates ocean bathymetry heights from an incomplete data set. This was achieved using free-air gravity anomalies obtained from satellite radar altimetry data. Through the Gravity-Geologic Method (GGM), the anomaly data was used to estimate missing data points from a set of control points taken from the General Bathymetric Chart of the Oceans (GEBCO) data set. The produced bathymetry map correlated more with the existing bathymetry from the GEBCO data set. Some error can be observed in the produced bathymetry map, but it was shown that accurate bathymetry could be predicted from an incomplete set of data using the GGM over the South China Sea study region.

## **ACKNOWLEDGEMENTS**

Work on this thesis was carried out over the year 2017 as an Earth Science major within the School of Earth Sciences at The Ohio State University.

I would like to thank my advisor Professor C.K. Shum for providing direction and focus for my thesis and for providing me with what was needed to complete the work. I would also like to thank Chaoyang Zhang for guiding me through the project and providing me with the software and data necessary for the thesis. Lastly, I'd like to thank my fellow undergraduate students at the School of Earth Sciences for providing support and context for my thesis work.

## **LIST OF FIGURES**

1. Bathymetry from GGM Method
2. Bathymetry from GEBCO
3. Control Points from GEBCO
4. RMS of Inversion Bathymetry with GEBCO
5. Difference of ETOPO-GEBCO

## **INTRODUCTION**

The Gravity-Geologic Method (GGM) is a method by which elevations can be estimated using incomplete elevation data sets. In this case, GGM is being used to estimate the bathymetry of a marine environment. Obtaining accurate seafloor bathymetry is essential for a variety of applications such as nautical charts, historical geology, marine biology, and other research. This method was sourced from the article *Altimetry-Derived Gravity Predictions of Bathymetry by the Gravity-Geologic Method* (Kim et al, 2010). Within this article, GGM was used to create bathymetry predictions for Drake Passage from an incomplete set of control points. Similarly, the goal of this thesis is to use the GGM method as well as an incomplete set of control points taken from the General Bathymetric Chart of the Oceans (GEBCO) data set (<https://www.gebco.net>) to estimate elevations over the South China Sea study region.

## METHODS

Bathymetric data for the South China Sea was calculated using the Gravity-Geologic Method (GGM). This method was adopted from the article *Altimetry-Derived Gravity Predictions of Bathymetry by the Gravity-Geologic Method* (Kim et al, 2010). First, altimeter data over the South China Sea was obtained from the Geosat altimeter (geodetic phase) dataset. From the data, we calculate the free-air gravity anomaly observed from satellite radar altimetry using the following equation:

$$g_{OBS}(i) = g_{RES}(i) + g_{REG}(i) \quad (1)$$

where  $g_{OBS}$  is the observed free-air gravity anomaly,  $g_{REG}$  is the regional gravity field, and  $g_{RES}$  is the residual anomaly. Assuming a simple Bouguer slab model, the value for  $g_{RES}$  can be modeled by the following formula:

$$g_{RES}(i) = 2\pi G(\Delta\rho)(E(i) - D) \quad (2)$$

Through simple algebra, the formula can be restructured to model bedrock elevation as shown in the following equation:

$$E(i) = \frac{g_{RES}(i)}{2\pi G\Delta\rho} + D \quad (3)$$

where  $G$  is the Universal Gravitational Constant,  $\Delta\rho$  is the density contrast,  $E(i)$  is the bedrock elevation, and  $D$  is the reference datum elevation.  $D$  values are control points taken from pre-existing bathymetry data, but not a complete set of bathymetry data.  $g_{RES}$  values are calculated by interpolating the regional gravity field over the whole study area and then subtracting the  $g_{REG}$  from the  $g_{OBS}$ .

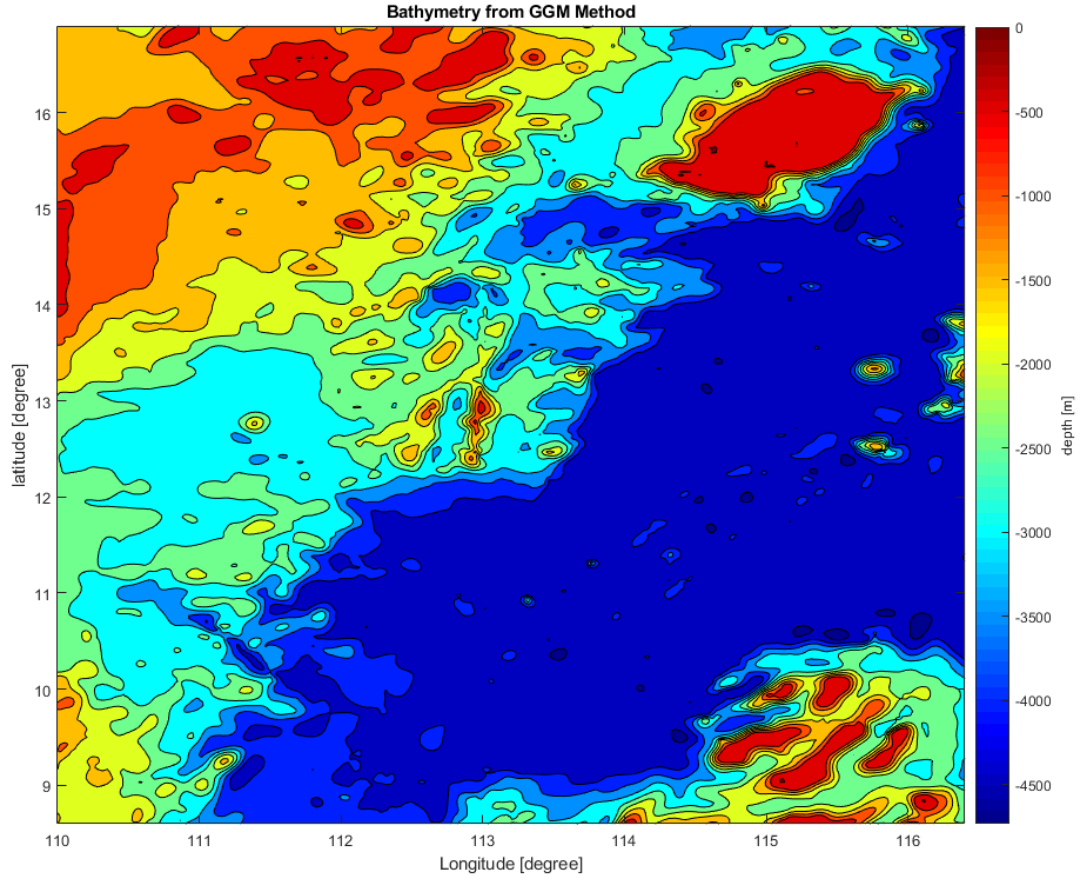
As for the density contrast value, it is first necessary to calculate the elevation estimate over the whole study area for different values of  $\Delta\rho$ . The resulting data sets were then compared with the control points as well as a different set of control points not used the elevation estimate that are designated as check points. The root-mean-square (RMS) differences of the estimates are then



plotted as a function of increasing density contrasts, as seen in Figure 4.  $\Delta\rho$  is then determined by finding a value at which the RMS differences with both the control points and check points level out and become stable. Some subjectivity is involved in this step. The elevation estimates are then calculated using the determined  $\Delta\rho$  value over the study area and a bathymetry map can be produced from the resulting data set.

## RESULTS

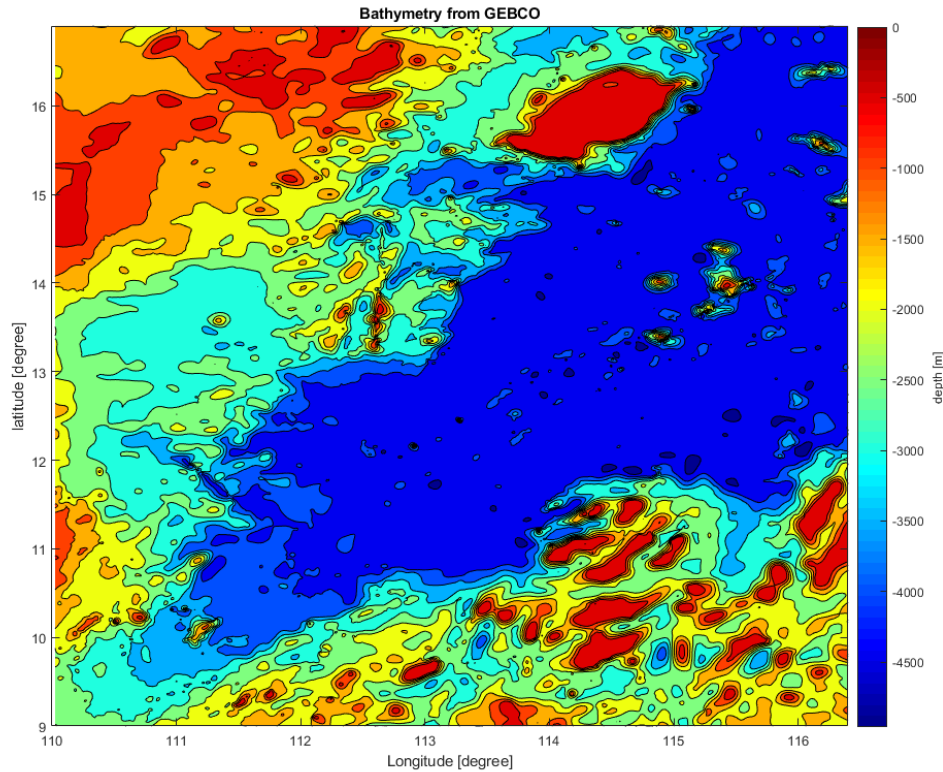
Through the GGM method, a plot of the bathymetry was created. The plot details the calculated elevation values over the area from  $8.6^{\circ}$ ,  $110.0^{\circ}$  to  $16.9^{\circ}$ ,  $116.4^{\circ}$  (latitude and longitude) in the South China Sea. This plot displays the main product of this research project.



**Figure 1:** Bathymetry determined from GEBCO data and Satellite Free-Air Anomaly data through the Gravity-Geologic Method (GGM) over the South China Sea.

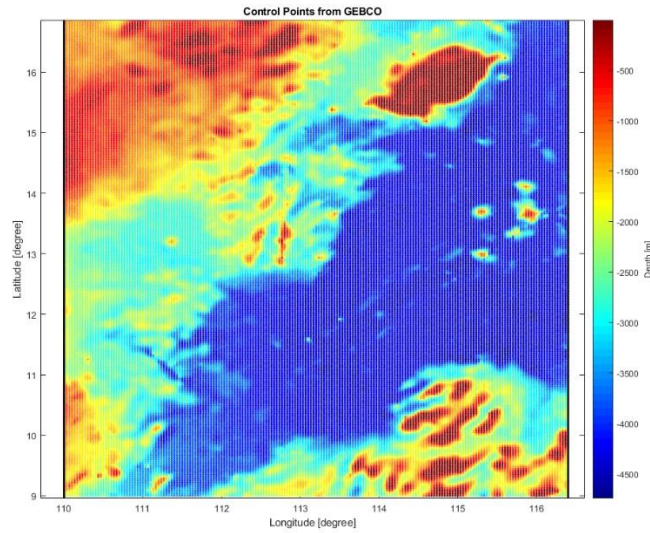
## DISCUSSION

The elevation estimates determined through the GGM method show a strong correlation to the full GEBCO bathymetry data set as displayed in Figure 2. The estimated values remain within a standard deviation of approximately 23 meters compared to the GEBCO values. A notable difference between the two sets is the small dark red spots of 0 m depth visible on the GGM-estimated bathymetry map. These spots likely represent islands that were not displayed in the GEBCO sounding data due to limitations of the observational tool. However, some, if not all, of these spots could be attributed to error from the GGM method. Another notable difference is that there are a few points, particularly near the higher-elevation shore, where the GGM estimates show lower elevation compared to the GEBCO bathymetry. This is likely error due to differences between the GGM data and the GEBCO sounding data concerning sensitivity to sediment and bedrock. The GGM bathymetry map also displays data at a reduced 1- arcminute resolution as compared to the GEBCO's 30 arcsecond data set due to the resolution of the altimeter data used in the study.



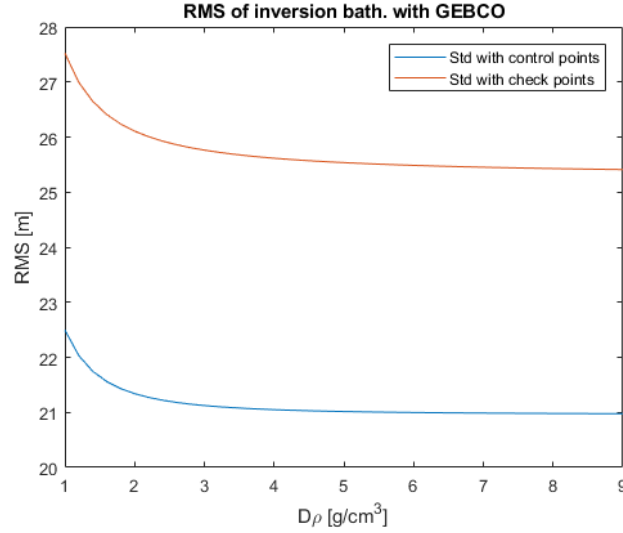
**Figure 2:** Bathymetry plot from GEBCO data set without use of GGM method

The primary advantage of the GGM method is producing elevation estimates from incomplete data sets. The bathymetry map shown in Figure 1 was developed using the GEBCO control points plotted in Figure 3. Points in the GGM bathymetry that correspond to these control points are entirely accurate, however the values estimated between these points may not be reliable where gravity analysis produces non-unique results. A reduction in control points would likely decrease the general accuracy of the GGM estimates.



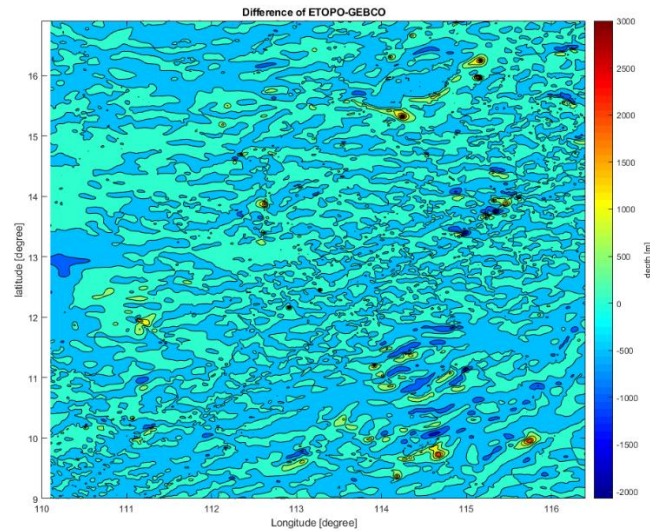
**Figure 3:** Plot of control points take from GEBCO data set to represent an incomplete bathymetry data set

The density contrast of  $3.0 \text{ g/cm}^3$  was determined using the method detailed in the methods section. The plot of RMS values as a function of increasing density contrast is shown in Figure 4. This value differs from a more natural density contrast value of  $\sim 1.7 \text{ g/cm}^3$  due to the marine environment of the study area. The density contrast between seawater and bathymetry is larger and more homogenous as compared to terrestrial environments. Also, the density contrast has more significance analytically rather than physically since it mitigates the limitations of using a single-density Bouguer slab model over multi-density terrain (Kim et al, 2010). However, bathymetry predictions could be made more accurate by using a non-linear model that would account for density variations.



**Figure 4:** Plot of RMS differences comparing GGM estimates to a set of control points as well as a set of check points

Another factor in creating the bathymetry map was determining whether the ETOPO1 or the newer GEBCO data set should be used for the control bathymetry data. Ultimately, as can be seen in Figure 4, the data sets were found to be very strongly correlated, with the average difference being 1.73 meters. There are only a few scattered areas where the depth varies by more than 200 meters. Thus, the decision was not a significant factor in the outcome and the GEBCO data set was chosen due to the fact it is more recent.



**Figure 5:** Plot of depth differences calculated from subtracting the GEBCO data set from the ETOPO1 data set over the area from  $8.6^0$ ,  $110.0^0$  to  $16.9^0$ ,  $116.4^0$  (latitude and longitude) in the South China Sea.

## **CONCLUSIONS**

The Gravity-Geologic Method (GGM) used in this study was shown to produce a reasonable estimate of elevation values over the South China Sea. These elevations values could be found using an incomplete set of bathymetry data as well as satellite altimeter data. However, instances of error can be seen that could be mitigated by future bathymetry prediction models.

## **RECOMMENDATIONS FOR FUTURE WORK**

- Use GGM method to derive bathymetry in other areas.
- Use of a non-linear model instead of the Bouguer slab formula to better account for the geometric and density properties of bathymetry.
- Use of satellite altimetry and the GGM method to create accurate global bathymetry data sets that are updated more frequently.
- Creation of an estimation model that can produce accurate bathymetry predictions with fewer control points.

## REFERENCES CITED

Jeong Woo Kim, Ralph R. B. von Frese, Bang Yong Lee, Daniel R. Roman, and Seong-Jae Doh (2010) Altimetry-Derived Gravity Predictions of Bathymetry by the Gravity-Geologic Method. *Pure Appl. Geophys.* 168 (2011), 815–826 DOI 10.1007/s00024-010-0170-5.

General Bathymetric Chart of the Oceans (GEBCO), <https://www.gebco.net>, Accessed September 2017.